NASA TM-81663

NASA Technical Memorandum 81663

NASA-TM-81663 19810007540

Propulsion System Mathematical Model For a Lift/Cruise Fan V/STOL Aircraft

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December 1980

NASA

PROPULSION SYSTEM MATHEMATICAL MODEL FOR A LIFT/CRUISE FAN V/STOL AIRCRAFT

by

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SUMMARY

A propulsion system mathematical model is documented that allows calculation of internal engine parameters during transient operation. A non-real-time digital computer simulation of the model is also presented. It can be used to investigate thrust response and modulation requirements as well as the impact of duty cycle on engine life and design criteria. Comparison of simulation results with steady-state cycle deck calculations showed good agreement. The model was developed for a specific 3-fan subsonic V/STOL aircraft application but it could be adapted for use with any similar lift/cruise V/STOL configuration.

N81-16055#

INTRODUCTION

A V/STOL aircraft propulsion system must supply the necessary lift forces and control moments during hover and vertical operations. To provide the desired aircraft handling qualities the propulsion system necessarily becomes an element in one or more high gain control loops. The result is a potential for undesired interactions between the flight control and the propulsion system. In the case of multiple engine systems there must be a means of power management and, possibly, accommodation of an engine failure.

In order to satisfy the unique requirements of V/STOL the propulsion system will have to meet certain thrust response, modulation and precision setting specifications. The harsh duty cycle of a V/STOL and the associated manipulation of the propulsion system will have an impact on engine life.

Mathematical models are certain to play an important role in the investigation of V/STOL propulsion requirements. A simple linear-transfer-function propulsion model is not adequate. Although a detailed aerothermodynamic model is not necessary it is desirable to be able to examine some internal engine parameters (e.g. turbine inlet temperature, compressor exit pressure).

The propulsion system mathematical model presented in this report was developed as part of a joint program with NASA Ames to model the research and technology (RTA) V/STOL aircraft shown in figure 1. The objective of the program was to provide data which could be used to investigate propulsion-system/flight-control interactions and propulsion requirements for subsonic V/STOL aircraft. This was accomplished by simulating the approach trajectory up to or just before hover while the aircraft was under automatic control. Approaches were made in the presence of disturbances such as turbulence, initial vertical and lateral offsets and engine failures. A non-real-time digital computer simulation of the models was used. The aircraft and flight control system models, some flight path results, and availability of data are discussed in reference 1. Additional information regarding the RTA characteristics and modeling are given in reference 2.

The objective of this report is to document the details of the propulsion system mathematical model as it was used in the RTA simulation. Although the model was developed for the RTA application it could be adapted for use with any similar lift/cruise V/STOL configuration. The model is nonlinear and allows monitoring of internal engine pressures and temperatures. Dynamic representations

of rotor inertias, heat soak, fuel control and pitch actuators are included in the model. Steady-state accuracy of the computer simulation is discussed and some transient results are presented. Listings of the digital computer program are also given with a brief discussion of each subroutine's function.

PROPULSION SYSTEM DESCRIPTION

The research and technology aircraft propulsion system consists of two lift/cruise turbofan engines, one turboshaft engine and one remote lift fan as shown in figures 1 and 2. The core engines are modeled after modified Detroit Diesel Allison XT701-AD-700 engines and the fans are based on Hamilton Standard 157.5-cm diameter variable pitch, low-pressure ratio fans. Additional information regarding the design of these units is given in references 3, 4, and 5. The lift/cruise fans are driven by the corresponding turboshaft engine low pressure (power) turbine through a reduction gear assembly. All three fans are connected by shafting through a combiner gearbox. This allows power transfer and prevents a loss of fan operation and hence thrust in the event of an engine failure. When a failure occurs, the failed engine power turbine is disconnected by means of an overrunning clutch to minimize the power loss. The remote fan is disengaged by declutching during conventional flight. Thrust amplitude is modulated primarily by varying fan-blade pitch angle. Total uninstalled thrust with all engines and fans operating at intermediate power is about 165 KN. Thrust is vectored by means of hooded nozzles on the aft engines and a louver system on the remote fan exit (fig. 1). The vectoring was included as part of the RTA airframe model.

PROPULSION SYSTEM MODEL DESCRIPTION

Engine Component Models

This section describes some of the propulsion mathematical model details and assumptions and, where necessary, methods of implementation.

Listings of the computer simulation are given in appendix B along with a brief description of each subroutine. The model equations can be readily determined from the FORTRAN program and are not summarized elsewhere. Definitions of the FORTRAN variables are given in appendix A.

A schematic of one turbofan engine is given in figure 3 and shows engine station numbers. The same station numbering is retained for the separate turboshaft and remote fan units unless noted otherwise. A computational flow diagram of the propulsion system model is given in figure 4. Each propulsion unit has its own representation. However, only two representations are shown in figure 4 because the turbofans, units 1 and 2 (fig. 2), are identical.

Required aircraft inputs to the model are altitude and Mach number. Altitude is used as the independent variable to determine ambient conditions from standard atmosphere tables. An additional input, DTT, is added to ambient temperature to simulate nonstandard-day temperature conditions. Mach number is used to compute free-stream total temperature and pressure. In this model the inlet is simply treated as having constant pressure recovery. Ordinarily recovery will depend on air speed and angle of attack (see ref. 6 for example). This is a more important consideration in a tilt nacelle application, especially in the flight regime where air speed is high (120 Kts) and angle of attack is high (60^{o}).

Fan temperature and pressure ratios and corrected airflow are found as functions of both fan blade pitch angle (ranging from -20^{o} to 7.3^{o}) and fan corrected speed (ranging from 70% to 110% of design). The lift/cruise fan pressure and temperature ratios are different at the hub (station 25) and tip (station 13). A fan stall-margin calculation is made based on a knowledge of fan corrected airflow and pressure ratio at stall as a function of fan blade angle and corrected speed. Fan-blade angle is input from the pitch actuator, which is assumed to be a simple first order lag with a .1 second time constant. Fan blade pitch rate is limited to 100^{o}/sec. During the RTA simulation study (ref.1), the pitch actuator was included as part of the power lever system model. The actuator model was basically the same as that just discussed except that a provision was made for a deadband in blade position. During the RTA study the actuator time constant and deadband size were varied to investigate the effects of thrust response and accuracy setting.

Compressor corrected airflow and adiabatic efficiency are determined as functions of compressor corrected speed (ranging from 65 to 107.5 percent of design).

Fan duct airflow for the turbofan units is computed by subtracting compressor airflow from fan airflow. All fan ducts are treated as having a fixed percentage total pressure loss.

Core flow is assumed to be the same as compressor airflow minus

compressor bleed. Fuel flow is added at the combustor and the bleed airflow is added back into the core flow at the turbines.

An iteration process is used to compute combustor total pressure PT4 which is assumed to be equal to compressor discharge static pressure PS3. The iteration loop (see ENGNyD subroutines) involves the heat-soak lead-lag dynamics and the temperature rise (TT4P-TT3) across the combustor due to the fuel flow input WFM. The temperature rise is found as a linear function of fuel/air ratio. Total pressure and temperature ratios across the high pressure turbine are assumed to be constants. Temperature, pressure and flow at the nozzles of the turbofan units are calculated assuming mixing of the fan duct and low-pressure turbine airstreams.

Fan, compressor and turbine power are computed from the flow rate through the machine times the enthalpy rise or drop across it. Enthalpy change is approximated as a constant specific heat times the change in temperature. The specific heat values in the equations were adjusted to give good agreement with the Detroit Diesel Allison steady-state cycle deck representation of the propulsion system. The time rate of change of rotor speed is calculated from the difference in power absorbed by the compressor or fan and the associated turbine power. Power losses due to gearing are neglected. High pressure rotor accelerations are calculated individually as shown in figure 4. However, since all three fans are connected by shafting, the low pressure rotor powers are summed as shown in figure 4. The time rate of change of fan speed NLDT is integrated to obtain fan speed which is the same for all three fans (see subroutine DVTOL). An option is available to allow declutching of the remote fan. In that case the power absorbed by the fan HPF3 and its inertia go to zero through a lag term. This feature was not used during simulation of the RTA. Another option allows simulation of an engine core failure. In that case the power output of the low pressure turbine drops to zero instantaneously. In the case of a turbofan failure the temperature of the nozzle airflow is set equal to the fan duct air temperature (i.e. no heating from core).

Thrust calculations are based on conventional momentum equations using the appropriate airflows and jet velocities. The nozzle exit temperature of the turbofan units is higher than that of the remote fan because of mixing with hot air from the core. The higher temperature results in higher nozzle velocity and consequently higher thrust. In the case of propulsion unit 3, only the fan is assumed to produce thrust (core thrust is neglected).

Fuel Control Model

A simplified block diagram of the fuel control is shown in figure 5. The dynamics of the compressor-inlet total-temperature (TT25) sensor and the fuel metering valve are implemented as first order lags. The time constant of the sensor is a function of airflow W25. Inputs to the fuel control are sensed compressor-inlet temperature T25SN, compressor exit static pressure PS3, high-pressure-rotor mechanical speed NH and demanded high-pressure-rotor corrected speed PCNHRD. There are no measurement dynamics associated with PS3 or NH. When used with the RTA simulation, the demanded corrected speed was determined from the power lever system output. The fuel control includes a proportional-plus-integral controller and fuel schedules to limit engine acceleration and deceleration. The MIN and MAX and limiter blocks shown in the diagram are part of the engine accel/decel limit and overtemperature protection. The output of a MIN or a MAX block is the smallest or largest of its inputs respectively. The control, as programmed, limits mechanical speed operation between 57 and 110 percent of design mechanical speed. The output of the fuel valve, WFM, goes to the combustor.

RESULTS AND DISCUSSION

Steady-state results from the propulsion system computer simulation were compared to results from a steady-state cycle deck developed by Detroit Diesel Allison (DDA). Both programs were run at fan corrected speeds ranging from 70 to 110 percent of design (fan blade pitch angle at design) and at fan blade pitch angles ranging from 1 to -12 degrees (fan corrected speed of 100%). In the fan corrected speed range of 90 to 110% the maximum thrust error was 4% and most other variables (e.g. fuel flow, turbine inlet temperature) were in error by less than 3%. At 70% fan corrected speed thrust and fuel flow were in error by 7% or less and temperatures and pressures were off by less than 3%.

Figure 6 illustrates the type of transient results that can be obtained for internal parameters from the propulsion simulation. Not all of the internal engine parameters that are available in the simulation are shown. The particular case shown was taken from reference 1 and is typical of the results obtained from the RTA simulation study. The results are for the last 120 seconds of an approach trajectory to hover. Failure of engine number 2 was programmed to occur at an altitude of 305m (approximately 30 seconds). Cycling of engine parameters such as turbine inlet temperature TT4 is evident as is the large jump in TT4 after the engine failure occurs.

In fact, at the end of the transient, TT4 approaches the 1 hour contingency rating of 1620 K specified in reference 5. Events such as these are of interest as to how they impact engine life and design criteria for V/STOL aircraft. Analysis of these data are beyond the scope of this report.

CONCLUDING REMARKS

A propulsion system model suitable for a non-real-time digital simulation of a lift/cruise fan V/STOL aircraft was presented. Steady-state agreement with detailed cycle deck calculations is good. The model has been integrated with the NASA-Ames mathematical model of the V/STOL Research and Technology Aircraft (RTA). It could be adapted for use with any similarly configured aircraft. The propulsion model is sufficiently detailed to allow investigation of thrust response requirements and low-cycle-fatigue/engine-life-deterioration during approach and vertical landing trajectories.

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APPENDIX A

DEFINITION OF PROPULSION SYSTEM FORTRAN VARIABLES

The following list defines the basic propulsion system parameters including all variables required to interpret the mathematical model equations. The general form of the variable names is ABCxy where ABC refers to the physical quantity, x refers to the station number (1 or 2 digits, see fig. 3), and y refers to the propulsion unit number (see figs. 1,2). The propulsion unit designation y is attached to the name only in subroutine DVTOL. Both SI and English units are given for each variable. When used with the RTA simulation, the computations, as documented in this report, were made using English units.

ALTENG	aircraft altitude, m (ft)
BETAF	fan blade pitch angle deg
BETFD or	
BETN	command to fan blade actuator
DELTAT	integration step size from LIFAN (typically .01), sec.
DETETO	transient time input from LIFAN (typically .05), sec
DTT	temperature increment above standard atmosphere, K(deg R)
EIE	initial fuel flow rate, Kg/sec (lbm/hr)
EOKL	output of first order lag in LIFAN when fan 3 clutch is engaged or disengaged
ETAC	core compressor efficiency, dimensionless
ETAR	inlet pressure recovery, dimensionless
FGROSS or	
FGROS	propulsion unit gross thrust, N (lbf)
FN	propulsion unit net thrust, N(lbf)
FRAM	ram drag, N(lbf)
FREQ2	heat soak lag frequency (see fig. 4) rad/sec
FREQ4	heat soak lag frequency (see fig. 4) rad/sec
HPF	power absorbed by fan, W(hp)
HP1T	power generated by low pressure turbine, W(hp)
HP2C	power absorbed by core compressor, W(hp)
HP2T	power generated by high pressure turbine, W(hp)
IMODE	< 0 for initialization pass
	$\geq$ 0 for transient run
NH	compressor speed, rpm
NHDT	compressor acceleration, rpm/sec
NL	fan speed, rpm
NLDT	fan acceleration, rpm/sec
P,PS	static pressure, N/cm**2 (psi)
PCNHD or	
PCNHRD	commanded compressor corrected speed, % of design

PCNHR	compressor corrected speed, % of design
PCNLR	fan corrected speed, % of design
PRSTL	fan stall pressure ratio for given PCNLR
PS3GS	guess for compressor exit static pressure in iteration loop (see ENGNyD subroutines), N/CM**2 (psi)
PT	total pressure, N/CM**2(psi)
P13Q2	fan tip total pressure ratio
P25Q2	fan hub total pressure ratio
SM	fan stall margin
T	static temperature, K(deg R)
TAUT25	compressor inlet temperature sensor time constant, sec
TAU1	heat soak dynamics time constant (see fig. 4), sec
TAU3	heat soak dynamics time constant (see fig. 4), sec
TT	total temperature, K (deg R)
TT3P	compressor exit total temperature before heat soak K (deg R)
TT4P	combustor exit total temperature before heat soak, K (deg R)
T13Q2	fan tip total temperature ratio
T25Q2	fan hub total temperature ratio
T25SN	output of compressor inlet total temperature sensor, K(deg R)
V	flow velocity, m/sec
VCLUCH	signal from LIFAN indicating when fan 3 is engaged (=1.) or disengaged (=0.)
VJ3	propulsion unit 3 low pressure rotor moment of inertia, kg-m (slug-ft)
W	inlet and engine core airflow rate, kg/sec (lbm/sec)
WA	fan duct airflow rate, kg/sec (lbm/sec)
WFH	fuel flow rate, kg/hr (lbm/hr)
WFI	output of fuel controller integrator, kg/hr (lbm/hr)
WFM	fuel flow rate, kg/sec (lbm/sec)
WG	mass flow rates downstream of combustor (includes fuel flow), kg/sec (lbm/sec)
WSTL	fan stall airflow for given PCNLR, kg/sec (lbm/sec)
W1R	fan corrected airflow, kg/sec (lbm/sec)
W25R	compressor corrected airflow, Kg/sec (lbm/sec)
XFAIL	flag to indicate engine failure (1.0 for engine operating, 0. for engine failed)
XNPCT	fan mechanical speed, %of design

APPENDIX B

DESCRIPTIONS AND LISTINGS OF DIGITAL COMPUTER SUBROUTINES

Subroutine DVTOL

This is the main controlling routine for the propulsion system computer program. It is assumed that DVTOL is called from a main program or another subroutine that supplies the aircraft altitude ALTENG and Mach number XMACH as well as initialization constants, control flags (e.g. XFAIL) and any other required inputs. References to LIFAN in the comment statements of DVTOL refer to input from or output to the power lever system part of the RTA airframe model. DVTOL sets up the initial conditions and controls the flow of the program during the dynamic segment. Output statements have been omitted, but just about all fan and engine variables are available via the COMMON statements.

```
      SUBROUTINE DVTOL
C     AS CONVERTED FOR LIFAN
C
      COMMON /FMEMR/IX(60),JY(60),IERR(60)
      COMMON /INTVAL/DT1,DT2,ICOUNT
      COMMON /XFLOAT/A(500)/IFIXED/IA(200)
      COMMON /YFLOAT/B(300)
      REAL NL1,NL2,NL3,NH1,NH2,NH3,NLDT1,NLDT2,NLDT3,NHDT1,NHDT2,NHDT3,MNO
      COMMON /XX1/ ALT,MNO,AE8,CV8,CV18,PS3GS,PT8GS,QX
      COMMON /XX2/XALT(8),ZPFA(8),ZTFA(8),XPCNH2(16),ZETAC(16),-
     A XPCNH1(12),ZW25R(12),XF18(17),ZF18(17),XF81(10),ZF81(10),YY(50),DYDT(50)
      COMMON /FAN/ XBETA(7),YPCNLR(5),ZFFLOW(7,5),ZFTPR(7,5),ZFTTR(7,5)
      COMMON /HUB/ XBETA1(8),ZFHPR(8,5),ZFHTR(8,5)
      COMMON /YY1/ NL1,NH1,T3L1,T4L1,PT0SN1,T12SN1,T3SN1,ERLIN1,X181,T25SN1,-
     A QMVLG1,XMV1,BETAF1,XXA1,XXB1,WFI1
      COMMON /DYDT1/ NLDT1,NHDT1,T3LDT1,T4LDT1,PT0DT1,T12DT1,T3SDT1,ERNDT1,-
     A X18DT1,T25DT1,QMVDT1,XMVDT1,BETDT1,XXADT1,XXBDT1,WFIDT1,WFHDT1
      COMMON /SIDE1/-
     A A181,WFH1,PCNLD1,XXKL1,XXKP1,P01,T01,P111,T111,TT21,-
     B V01,PCNLR1,P13Q21,T13Q21,W11,PT21,PT131,TT131,PT251,TT251,-
     C PCNHR1,W25R1,W251,P13181,PT181,P0Q181,WA181,W31,WG41,WFM1,-
     D PS31,PT31,P3Q251,TT31,TT41,PT41,TT421,WG81,PT81,PT421,-
     E TT81,HP1T1,HPF1,HP2T1,WFHI1,HP2C1,P0Q81,V81,V181,FGROS1,-
     F FRAM1,FN1,WFMPS1,WFMPT1,WFMTT1,WFMQK1,PHI1,PS3C1,WFMAC1,FNZ181,-
     G WG181,WFMDC1,XMVDC1,TT181,ERRNL1,PCNHD1,QNH1,QMV1,HPX1,BETFD1,-
     H SM1
      COMMON /YY2/ NL2,NH2,T3L2,T4L2,PT0SN2,T12SN2,T3SN2,ERLIN2,X182,T25SN2,-
     A QMVLG2,XMV2,BETAF2,XXA2,XXB2,WFI2
      COMMON /DYDT2/ NLDT2,NHDT2,T3LDT2,T4LDT2,PT0DT2,T12DT2,T3SDT2,ERNDT2,-
     A X18DT2,T25DT2,QMVDT2,XMVDT2,BETDT2,XXADT2,XXBDT2,WFIDT2,WFHDT2
      COMMON /SIDE2/-
     A A182,WFH2,PCNLD2,XXKI2,XXKP2,P02,T02,P112,T112,TT22,-
     B V02,PCNLR2,P13Q22,T13Q22,W12,PT22,PT132,TT132,PT252,TT252,-
     C PCNHR2,W25R2,W252,P13182,PT182,P0Q182,WA182,W32,WG42,WFM2,-
     D PS32,PT32,P3Q252,TT32,TT42,PT42,TT422,WG82,PT82,PT422,-
     E TT82,HP1T2,HPF2,HP2T2,WFHI2,HP2C2,P0Q82,V82,V182,FGROS2,-
     F FRAM2,FN2,WFMPS2,WFMPT2,WFMTT2,WFMQK2,PHI2,PS3C2,WFMAC2,FNZ182,-
     G WG182,WFMDC2,XMVDC2,TT182,ERRNL2,PCNHD2,QNH2,QMV2,HPX2,BETFD2,-
     H SM2
      COMMON /YY3/ NL3,NH3,T3L3,T4L3,PT0SN3,T12SN3,T3SN3,ERLIN3,X183,T25SN3,-
     A QMVLG3,XMV3,BETAF3,XXA3,XXB3,WFI3
      COMMON /DYDT3/ NLDT3,NHDT3,T3LDT3,T4LDT3,PT0DT3,T12DT3,T3SDT3,ERNDT3,-
     A X18DT3,T25DT3,QMVDT3,XMVDT3,BETDT3,XXADT3,XXBDT3,WFIDT3,WFHDT3
      COMMON /SIDE3/-
     A A183,WFH3,PCNLD3,XXKI3,XXKP3,P03,T03,P113,T113,TT23,-
     B V03,PCNLR3,P13Q23,T13Q23,W13,PT23,PT133,TT133,PT253,TT253,-
     C PCNHR3,W25R3,W253,P13183,PT183,P0Q183,WA183,W33,WG43,WFM3,-
     D PS33,PT33,P3Q253,TT33,TT43,PT43,TT423,WG83,PT83,PT423,-
     E TT83,HP1T3,HPF3,HP2T3,WFHI3,HP2C3,P0Q83,V83,V183,FGROS3,-
     F FRAM3,FN3,WFMPS3,WFMPT3,WFMTT3,WFMQK3,PHI3,PS3C3,WFMAC3,FNZ183,-
     G WG183,WFMDC3,XMVDC3,TT183,ERRNL3,PCNHD3,QNH3,QMV3,HPX3,BETFD3,-
     H SM3
C     ADDED FOR LIFAN CONVERSION
```

```
      DIMENSION EIE(3),BET(3),DWF(3),DMF(3),FGU(3),OMEG(3),OMEGF(3)
      DIMENSION PCNHC(3)
      EQUIVALENCE (XMACH,A(71)),(ALTENG,A(83)),(D2R,A(358))
      EQUIVALENCE (DELT2,A(168)),(BET(1),B(47)),(EIE(1),B(285))
      EQUIVALENCE (XNPCT,B(121)),(DWF(1),B(90)),(FGU(1),B(95))
      EQUIVALENCE (OMEG(1),B(62)),(OMEGF(1),B(105)),(DETETO,A(168))
      EQUIVALENCE (DMF(1),B(87)),(OMEG(1),B(62)),(OMEGF(1),B(105))
      EQUIVALENCE (XNPCT3,B(293)),(EOKL,B(294)) ,(DTPRNT,A(2)),(TIME,A(3))
      EQUIVALENCE (PCNHC(1),B(290)),(IA(1),IMODE),(PROTIM,A(4)),(XFAIL,A(5))
      EQUIVALENCE (B(120),VCLUCH),(B(294),EOKL),(DELTAT,A(169)),(DTT,A(170))
      EQUIVALENCE (ETAR,A(6))
C
      IF(IMODE.GE.0) GO TO 233
      DO 2 I=1,60
      IX(I)=1
      JY(I)=1
      IERR(I)=1
2     CONTINUE
C*****INITIAL CONDITIONS
C    INPUT FOR FAN BLADE PITCH FROM LIFAN
      YY(1)=3600.
      YY(2)=14528.
      YY(3)=1221.
      YY(4)=2493.
      YY(5)=EIE(1)
      YY(6)=EIE(2)
      YY(7)=EIE(3)
      YY(8)=0.0
      YY(9)=0.0
      YY(10)=583.8
      YY(11)=0.0
      YY(12)=0.0
      YY(13)=BETAF1
      YY(14)=0.0
      YY(15)=3600.
      YY(16)=14528.
      YY(17)=1221.
      YY(18)=2493.
C    FUEL FLOW INPUT FROM LAST WFH
      YY(19)=EIE(1)
      YY(20)=EIE(2)
      YY(21)=EIE(3)
C
C
      YY(22)=0.0
      YY(23)=0.0
      YY(24)=583.8
      YY(25)=0.0
      YY(26)=0.0
      YY(27)=BETAF2
      YY(28)=0.0
      YY(29)=0.0
      YY(30)=3600.
```

```
      YY(31)=14576.
      YY(32)=1197.
      YY(33)=2539.
      YY(34)=0.0
      YY(35)=0.0
      YY(36)=0.0
      YY(37)=0.0
      YY(38)=0.0
      YY(39)=549.7
      YY(40)=0.0
      YY(41)=0.0
      YY(42)=BETAF3
      YY(43)=0.0
      YY(44)=0.0
C*****TIMING CONSTANTS
      DT1=DELTAT
      DT2=0.5*DELTAT
      TIME=0.0
  233 CONTINUE
      WFHSV1=0.
      WFHSV2=0.
      WFHSV3=0.
      KFUEL=0
C*****MACH NUMBER INPUT FROM LIFAN
C
      MNO=XMACH
C*****ALTITUDE INPUT FROM LIFAN
C
      ALT=ALTENG
C*****ENGINE ENVIRONMENTAL CALCULATIONS
      P01=FUN1(1,8,XALT,ZPFA,ALT)
      T01=FUN1(2,8,XALT,ZTFA,ALT)
C*****NONSTANDARD DAY TEMP.
      T01=T01+DTT
      T02=T01
      T03=T01
      P02=P01
      P03=P01
C*****INLET CALCULATIONS
      PT21=ETAR*P01*(1.+0.2*MNO**2)**3.5
      TT21=T01*(1.+0.2*MNO**2)
      PT22=PT21
      PT23=PT21
      TT22=TT21
      TT23=TT21
C*****BET AND PCNHC INPUT FROM LIFAN
      BETAF1=BET(1)
      BETAF2=BET(2)
      BETAF3=BET(3)
      PCNHD1=13.89*(PCNHC(1))**.2+28.87
      PCNHD2=13.89*(PCNHC(2))**.2+28.87
      PCNHD3=17.07*(PCNHC(3))**.2+16.11
      VJ3=VCLUCH*14.4
```

```
      BETFD1=BETAF1
      BETFD2=BETAF2
      BETFD3=BETAF3
C    SET RUNTIM = TO DT2 FROM LIFAN
      RUNTIM = DETETO
      IQUIT=RUNTIM/DELTAT+.1
C     WRITE(6,101)
C*****DYNAMIC SEGMENT OF MODEL
      DO 700 LOOP1=1,IQUIT
      ICOUNT=-1
600   CONTINUE
      NL1=YY(1)
      NH1=YY(2)
      T3L1=YY(3)
      T4L1=YY(4)
      WFI1=YY(5)
      WFI2=YY(6)
      WFI3=YY(7)
      ERLIN1=YY(8)
      TWIST=YY(9)
      T25SN1=YY(10)
      QMVLG1=YY(11)
      XMV1=YY(12)
      DUM14=YY(14)
      NL2=YY(15)
      NH2=YY(16)
      T3L2=YY(17)
      T4L2=YY(18)
      WFH1=YY(19)
      WFH2=YY(20)
      WFH3=YY(21)
      ERLIN2=YY(22)
      DUM24=YY(23)
      T25SN2=YY(24)
      QMVLG2=YY(25)
      XMV2=YY(26)
      DUM25=YY(28)
      DUM26=YY(29)
      NL3=YY(30)
      NH3=YY(31)
      T3L3=YY(32)
      T4L3=YY(33)
      DUM31=YY(34)
      DUM32=YY(35)
      DUM33=YY(36)
      ERLIN3=YY(37)
      DUM34=YY(38)
      T25SN3=YY(39)
      QMVLG3=YY(40)
      XMV3=YY(41)
      DUM35=YY(43)
      DUM36=YY(44)
      CALL ENGNID
```

```
      CALL ENGN2D
      CALL ENGN3D
      IF(IMODE.LT.0) GO TO 216
      ERNDT1=PCNLD1-NL1/36.
      ERNDT2=ERNDT1
      ERNDT3=ERNDT1
      HP1T1=HP1T1*XFAIL
      HP1TT=HP1T1+HP1T2+HP1T3
      HPFT=HPF1+HPF2+HPF3
      DELHP=HP1TT-HPFT
      NLDT1=(50154./(2.*14.4+VJ3))*DELHP/NL1
      IF(ABS(NLDT1) .GT. 9549.3) NLDT1=SIGN(2549.3,NLDT1)
      NLDT2=NLDT1
      NLDT3=NLDT1
      DYDT(1)=NLDT1
      DYDT(2)=NHDT1
      DYDT(3)=T3LDT1
      DYDT(4)=T4LDT1
      DYDT(5)=WFIDT1
      DYDT(6)=WFIDT2
      DYDT(7)=WFIDT3
      DYDT(8)=ERNDT1
      DYDT(9)=0.0
      DYDT(10)=T25DT1
      DYDT(11)=QMVDT1
      DYDT(12)=XMVDT1
      DYDT(13)=0.
      DYDT(14)=0.0
      DYDT(15)=NLDT2
      DYDT(16)=NHDT2
      DYDT(17)=T3LDT2
      DYDT(18)=T4LDT2
      DYDT(19)=WFHDT1
      DYDT(20)=WFHDT2
      DYDT(21)=WFHDT3
      DYDT(22)=ERNDT2
      DYDT(23)=0.0
      DYDT(24)=T25DT2
      DYDT(25)=QMVDT2
      DYDT(26)=XMVDT2
      DYDT(27)=0.
      DYDT(28)=0.0
      DYDT(29)=0.0
      DYDT(30)=NLDT3
      DYDT(31)=NHDT3
      DYDT(32)=T3LDT3
      DYDT(33)=T4LDT3
      DYDT(34)=0.0
      DYDT(35)=0.0
      DYDT(36)=0.0
      DYDT(37)=ERNDT3
      DYDT(38)=0.0
      DYDT(39)=T25DT3
```

```
      DYDT(40)=QMVDT3
      DYDT(41)=XMVDT3
      DYDT(42)=0.
      DYDT(43)=0.0
      DYDT(44)=0.0
C*****INTEGRATE DIFFERENTIALS
      CALL EULERM(DYDT,YY)
      YY(30)=YY(30)*EOKL
      IF (ICOUNT) 600,610,650
 650  CONTINUE
      KFUEL=KFUEL+1
      WFHSV1=WFH1+WFHSV1
      WFHSV2=WFH2+WFHSV2
      WFHSV3=WFH3+WFHSV3
C*****UPDATE TIME
      TIME=TIME+DELTAT
      GO TO 700
 610  CONTINUE
      GO TO 600
 700  CONTINUE
C    OUTPUT VALUES FOR LIFAN
     WFHOU1 = WFHSV1/KFUEL
     WFHOU2 = WFHSV2/KFUEL
     WFHOU3 = WFHSV3/KFUEL
  216 XNPCT=NL1/36.
      XNPCT3=NL3/36.
      DWF(1)=WFHOU1
      DWF(2)=WFHOU2
      DWF(3)=WFHOU3
      FGU(1)=FGROS1
      FGU(2)=FGROS2
      FGU(3)=FGROS3
      DMF(1)=WA181*.0310559
      DMF(2)=WA182*.0310559
      DMF(3)=WA183*.0310559
      OMEG(1)=NH1*.1047197
      OMEG(2)=NH2*.1047197
      OMEG(3)=NH3*.1047197
      OMEGF(1)=NL1*.1047197
      OMEGF(2)=NL2*.1047197
      OMEGF(3)=NL3*.1047197
      EIE(1)=WFH1
      EIE(2)=WFH2
      EIE(3)=WFH3
  215 RETURN
      END
```

Subroutine ENGN1D

This subroutine is called from DVTOL and computes variables for turbofan propulsion unit number one (see fig. 1). Included are fan, core, core inlet temperature sensor, core speed (fuel) control, and fan-blade pitch actuator parameters. (It should be recalled that the pitch actuator was handled outside the propulsion model for the RTA simulation.) Derivative terms are also calculated except for fan acceleration NLDT, which requires inputs from all three propulsion units.

```
      SUBROUTINE ENGN1D
      REAL MNO,NL,NLDT,NH,NHDT,NHD,NHERR
      COMMON /XX1/ ALT,MNO,AE8,CV8,CV18,PS3GS,PT8GS,QX
      COMMON /XX2/ XALT(8),ZPFA(8),ZTFA(8),XPCNH2(16),ZETAC(16),-
     A XPCNH1(12),ZW25R(12),XF18(17),ZF18(17),XF81(10),ZF81(10),YY(50),DYDT(50)
      COMMON /FAN/ XBETA(7),YPCNLR(5),ZFFLOW(7,5),ZFTPR(7,5),ZFTTR(7,5)
      COMMON /HUB/ XBETA1(8),ZFHPR(8,5),ZFHTR(8,5)
      COMMON/CORE/XNH(24),YTT25(5),ZWFSCH(24,5)
      COMMON/FANSTL/XBETA2(5),ZWSTL(5,5),ZPRSTL(5,5)
      COMMON /YY1/ NL,NH,T3L,T4L,PT0SN,T12SN,T3SN,ERLINT,X18,T25SN,QMVLG,XMV,-
     A BETAF,XXA,XXB,WFI
      COMMON /XFLOAT/A(500)
      EQUIVALENCE (XFAIL,A(5))
      COMMON /DYDT1/ NLDT,NHDT,T3LDT,T4LDT,PT0SDT,T12SDT,T3SDT,ERNLDT,X18DT,-
     A TT25DT,QMVLDT,XMVDT,BETADT,XXADT,XXBDT,WFIDT,WFHDT
      COMMON /SIDE1/-
     A A18   ,WFH   ,PCNLRD,XXKI  ,XXKP  ,P0    ,T0    ,P11   ,T11   ,TT2   ,-
     B V0    ,PCNLR ,P13Q2 ,T13Q2 ,W1    ,PT2   ,PT13  ,TT13  ,PT25  ,TT25  ,-
     C PCNHR ,W25R  ,W25   ,P13Q18,PT18  ,P0Q18 ,WA18  ,W3    ,WG4   ,WFM   ,-
     D PS3   ,PT3   ,P3QP25,TT3   ,TT4   ,PT4   ,TT42  ,WG8   ,PT8   ,PT42  ,-
     E TT8   ,HP1T  ,HPF   ,HP2T  ,WFHI  ,HP2C  ,P0Q8  ,V8    ,V18   ,FGROSS,-
     F FRAM  ,FN    ,WFMPSS,WFMPTP,WFMPST,WFMQK ,PHI   ,PS3C  ,WFACC,FNZ18 ,-
     G WG18  ,WFDEC,XMVDEC,TT18  ,ERRNL ,PCNHRD,QNH   ,QMV   ,HPX   ,BETAFD,-
     H SM
      ITR3S=0
      RTH2=SQRT(TT2/518.67)
      QRTH2=1./RTH2
      RTT0=SQRT(T0)
      V0=49.018*MNO*RTT0
C*****ENGINE MODEL
  600 CONTINUE
C*****FAN CALCULATIONS
      PCNLR=NL/36./(SQRT(TT2/556.))
      W1R=FUN2(10,7,5,XBETA,YPCNLR,ZFFLOW,BETAF,PCNLR)
      P13Q2=FUN2(11,7,5,XBETA,YPCNLR,ZFTPR,BETAF,PCNLR)
      T13Q2=FUN2(12,7,5,XBETA,YPCNLR,ZFTTR,BETAF,PCNLR)
      IF(W1R .LT. 0.) W1R=0.
      IF(T13Q2 .LT. 1.) T13Q2=1.
      IF(P13Q2 .LT. 1.) P13Q2=1.
      W1=W1R*(PT2/14.696)*QRTH2
C*****FAN STALL MARGIN CALCULATIONS
      WSTL=FUN2(4,5,5,XBETA2,YPCNLR,ZWSTL,BETAF,PCNLR)
      PRSTL=FUN2(5,5,5,XBETA2,YPCNLR,ZPRSTL,BETAF,PCNLR)
      SM=100.*((PRSTL*W1R/P13Q2/(WSTL*.0929*17.18/.4536))-1.)
      P25Q2=FUN2(13,8,5,XBETA1,YPCNLR,ZFHPR,BETAF,PCNLR)
      T25Q2=FUN2(14,8,5,XBETA1,YPCNLR,ZFHTR,BETAF,PCNLR)
      PT13=P13Q2*PT2
      TT13=T13Q2*TT2
      PT25=P25Q2*PT2
      TT25=T25Q2*TT2
      QRTH25=1.0/SQRT(TT25*1.928E-3)
C*****COMPRESSOR CALCULATIONS
      PCNHR=NH/154.5/(SQRT(TT25/605.4))
```

```
      W25R=1.013*FUN1(15,12,XPCNH1,ZW25R,PCNHR)
      ETAC=FUN1(16,16,XPCNH2,ZETAC,PCNHR)
      W25=W25R*.068046*PT25*QRTH25
C*****FAN DUCT CALCULATIONS
      PT18=.978*PT13
      WA18=W1-W25
   34 W3=.9036*W25
      WFM=WFH/3600.
      WG4=WFM+W3+.025*W25
      FREQ2=0.0104*W3
      TAU1=0.843/FREQ2
      FREQ4=0.0240*WG4
      TAU3=0.868/FREQ4
C*****ITERATE FOR COMPRESSOR DISCHARGE STATIC PRESSURE
C*******HEAT SOAK DYNAMICS
      KPS3=0
   35 ITR3S=ITR3S+1
      PS3=PS3GS
      IF(PS3.LT.1.0) PS3=1.0
      PT3=1.057*PS3
      P3QP25=PT3/PT25
      T3Q25=1.+(P3QP25**.2857-1.)/ETAC
      TT3P=T3Q25*TT25
      T3LDT=(TT3P-T3L)*FREQ2
      TT3=TAU1*T3LDT+T3L
      TT4P=53233.*(WFM/W3)+159.+TT3
      T4LDT=(TT4P-T4L)*FREQ4
      TT4=TAU3*T4LDT+T4L
      PS3=.0812*WG4*SQRT(TT4)
      ERR=PS3-PS3GS
      CALL CNVRG1(2,ERR,PS3,PS3GS,.0002,ITR3S,KPS3)
      IF(KPS3.EQ.1)GO TO 40
      GO TO 35
   40 CONTINUE
      PT4=PS3
C*****HIGH AND LOW TURBINE EXIT CONDITIONS
      TT42=.7897*TT4
      WG8=W25+WFM
      PT42=.300*PT4
      PT8=.01557*WG8+.919*PT18
      TT8Q42=1.-(1.-(PT8/PT42)**.248)*.866
      TT8=TT42*TT8Q42
      IF(XFAIL .LT. 0.1) TT8=TT25
C*****FAN ROTOR DYNAMICS
      HP1T=.3817*WG8*(TT42-TT8)
      HPF=.3356*(W25*(TT25-TT2)+WA18*(TT13-TT2))
C*****CORE ROTOR DYNAMICS
      HP2T=.417*WG4*(TT4-TT42)
      HP2C=.369*W3*(TT3-TT25)
      NHDT=37710./NH*(HP2T-HP2C)
C*****THRUST CALCULATIONS
      WG18=WG8+WA18
      TT18=(WA18*TT13+WG8*TT8)/WG18
```

```
      P0Q18=P0/PT18
      FNZ18=FUN1(17,17,XF18,ZF18,P0Q18)
C*****OR SUBSTITUTE FNZ18=SQRT(1.-P0Q18**(2./7.))
      V18=109.6*SQRT(TT18)*FNZ18*CV18
      FGROSS=WG18*V18*.0311
   54 FRAM=W1*V0*0.031085
      FN=FGROSS-FRAM
C*****CORE INLET AIR TEMPERATURE SENSOR
      TAUT25=FUN1(18,10,XF81,ZF81,1.38*W25)
      TT25DT=(TT25-T25SN)/TAUT25
      TH25SN=T25SN/605.4
      RTH25S=SQRT(TH25SN)
C*****FUEL CONTROL
      NHD=154.5*PCNHRD*RTH25S
      NHD=AMIN1(NHD,17000.)
      NHD=AMAX1(NHD,8795.)
      NHERR=NH-NHD
      CONST=SQRT(WFH)*NH*1.494E-6
      WFPROP=-2.29*NHERR*CONST
      CON=-3.21
      IF(WFC2.NE.WFGV) CON=0.
      WFIDT=NHERR*CON*CONST
      WFGOV=WFPROP+WFI
      WFSCH=FUN2(19,24,5,XNH,YTT25,ZWFSCH,NH,T25SN)
      WFACMX=-.0134*NH+234.1
      IF(WFSCH.GT.WFACMX) WFSCH=WFACMX
      IF(PS3.LE.200.) PC=PS3
      IF(PS3.GT.200.) PC=200.+(PS3-200.)*(-2.)
      WFACC=WFSCH*PC
      WFDEC=.385*WFACC
      WFC1=AMIN1(WFACC,WFGOV)
      WFC1=AMAX1(WFC1,WFDEC)
      WFC1=AMIN1(WFC1,4438.)
      WFC1=AMAX1(WFC1,295.858)
      WFC2=WFC1
      WFGV=WFGOV
      WFHDT=(WFC1-WFH)/.05
C*****FAN PITCH ACTUATOR
      BETADT=10.*(BETAFD-BETAF)
      IF(ABS(BETADT).GT.100.) BETADT=SIGN(100.,BETADT)
      RETURN
      END
```

Subroutine ENGN2D

This subroutine is called from DVTOL and computes variables for turbofan propulsion unit number 2. It is essentially the same as ENGN1D except that it was not programmed to include the core failure option XFAIL of ENGN1D. This feature could easily be added.

```
      SUBROUTINE ENGN2D
      REAL MN0,NL,NLDT,NH,NHDT,NHD,NHERR
      COMMON /XX1/ ALT,MN0,AE8,CV8,CV18,PS3GS,PT8GS,QX
      COMMON /XX2/ XALT(8),ZPFA(8),ZTFA(8),XPCNH2(16),ZETAC(16),-
     A XPCNH1(12),ZW25R(12),XF18(17),ZF18(17),XF81(10),ZF81(10),YY(50),DYDT(50)
      COMMON /FAN/ XBETA(7),YPCNLR(5),ZFFLOW(7,5),ZFTPR(7,5),ZFTTR(7,5)
      COMMON /HUB/ XBETA1(8),ZFHPR(8,5),ZFHTR(8,5)
      COMMON/CORE/XNH(24),YTT25(5),ZWFSCH(24,5)
      COMMON/FANSTL/XBETA2(5),ZWSTL(5,5),ZPRSTL(5,5)
      COMMON /YY2/ NL,NH,T3L,T4L,PT0SN,T12SN,T3SN,ERLINT,X18,T25SN,QMVLG,XMV,-
     A BETAF,XXA,XXB,WFI
      COMMON /DYDT2/ NLDT,NHDT,T3LDT,T4LDT,PT0SDT,T12SDT,T3SDT,ERNLDT,X18DT,-
     A TT25DT,QMVLDT,XMVDT,BETADT,XXADT,XXBDT,WFIDT,WFHDT
      COMMON /SIDE2/-
     A A18    ,WFH    ,PCNLRD,XXKI   ,XXKP   ,P0     ,T0     ,P11    ,T11    ,TT2    ,-
     B V0     ,PCNLR  ,P13Q2  ,T13Q2  ,W1     ,PT2    ,PT13   ,TT13   ,PT25   ,TT25   ,-
     C PCNHR  ,W25R   ,W25    ,P13Q18,PT18    ,P0Q18  ,WA18   ,W3     ,WG4    ,WFM    ,-
     D PS3    ,PT3    ,P3QP25,TT3     ,TT4    ,PT4    ,TT42   ,WG8    ,PT8    ,PT42   ,-
     E TT8    ,HP1T   ,HPF    ,HP2T   ,WFHI   ,HP2C   ,P0Q8   ,V8     ,V18    ,FGROSS,-
     F FRAM   ,FN     ,WFMPSS,WFMPTP,WFMPST,WFMQK   ,PHI    ,PS3C   ,WFACC,FNZ18  ,-
     G WG18   ,WFDEC,XMVDEC,TT18    ,ERRNL  ,PCNHRD,QNH     ,QMV    ,HPX    ,BETAFD,-
     H SM
      ITR3S=0
      RTH2=SQRT(TT2/518.67)
      QRTH2=1./RTH2
      RTT0=SQRT(T0)
      V0=49.018*MN0*RTT0
C*****ENGINE MODEL
  600 CONTINUE
C*****FAN CALCULATIONS
      PCNLR=NL/36./(SQRT(TT2/556.))
      W1R=FUN2(20,7,5,XBETA,YPCNLR,ZFFLOW,BETAF,PCNLR)
      P13Q2=FUN2(21,7,5,XBETA,YPCNLR,ZFTPR,BETAF,PCNLR)
      T13Q2=FUN2(22,7,5,XBETA,YPCNLR,ZFTTR,BETAF,PCNLR)
      IF(W1R .LT. 0.) W1R=0.
      IF(T13Q2 .LT. 1.) T13Q2=1.
      IF(P13Q2 .LT. 1.) P13Q2=1.
      W1=W1R*(PT2/14.696)*QRTH2
C*****FAN STALL MARGION CALCULATIONS
      WSTL=FUN2(6,5,5,XBETA2,YPCNLR,ZWSTL,BETAF,PCNLR)
      PRSTL=FUN2(7,5,5,XBETA2,YPCNLR,ZPRSTL,BETAF,PCNLR)
      SM=100.*((PRSTL*W1R/P13Q2/(WSTL*.0929*17.18/.4536))-1.)
      P25Q2=FUN2(23,8,5,XBETA1,YPCNLR,ZFHPR,BETAF,PCNLR)
      T25Q2=FUN2(24,8,5,XBETA1,YPCNLR,ZFHTR,BETAF,PCNLR)
      PT13=P13Q2*PT2
      TT13=T13Q2*TT2
      PT25=P25Q2*PT2
      TT25=T25Q2*TT2
      QRTH25=1.0/SQRT(TT25*1.928E-3)
C*****COMPRESSOR CALCULATIONS
      PCNHR=NH/154.5/(SQRT(TT25/605.4))
      W25R=1.013*FUN1(25,12,XPCNH1,ZW25R,PCNHR)
      ETAC=FUN1(26,16,XPCNH2,ZETAC,PCNHR)
```

```
      W25=W25R*.068046*PT25*QRTH25
C*****FAN DUCT CALCULATIONS
      PT18=.978*PT13
      WA18=W1-W25
   34 W3=.9036*W25
      WFM=WFH/3600.
      WG4=WFM+W3+.025*W25
      FREQ2=0.0104*W3
      TAU1=0.843/FREQ2
      FREQ4=0.0240*WG4
      TAU3=0.868/FREQ4
C*****ITERATE FOR COMPRESSOR DISCHARGE STATIC PRESSURE
C*******HEAT SOAK DYNAMICS
      KPS3=0
   35 ITR3S=ITR3S+1
      PS3=PS3GS
      IF(PS3.LT.1.0) PS3=1.0
      PT3=1.057*PS3
      P3QP25=PT3/PT25
      T3Q25=1.+(P3QP25**.2857-1.)/ETAC
      TT3P=T3Q25*TT25
      T3LDT=(TT3P-T3L)*FREQ2
      TT3=TAU1*T3LDT+T3L
      TT4P=53233.*(WFM/W3)+159.+TT3
      T4LDT=(TT4P-T4L)*FREQ4
      TT4=TAU3*T4LDT+T4L
      PS3=.0812*WG4*SQRT(TT4)
      ERR=PS3-PS3GS
      CALL CNVRG1(5,ERR,PS3,PS3GS,.0002,ITR3S,KPS3)
      IF(KPS3.EQ.1)GO TO 40
      GO TO 35
   40 CONTINUE
      PT4=PS3
C*****HIGH AND LOW TURBINE EXIT CONDITIONS
      TT42=.7897*TT4
      WG8=W25+WFM
      PT42=.300*PT4
      PT8=.01557*WG8+.919*PT18
      TT8Q42=1.-(1.-(PT8/PT42)**.248)*.866
      TT8=TT42*TT8Q42
C*****FAN ROTOR DYNAMICS
      HP1T=.3817*WG8*(TT42-TT8)
      HPF=.3356*(W25*(TT25-TT2)+WA18*(TT13-TT2))
C*****CORE ROTOR DYNAMICS
      HP2T=.417*WG4*(TT4-TT42)
      HP2C=.369*W3*(TT3-TT25)
      NHDT=37710./NH*(HP2T-HP2C)
C*****THRUST CALCULATIONS
      WG18=WG8+WA18
      TT18=(WA18*TT13+WG8*TT8)/WG18
      P0Q18=P0/PT18
      FNZ18=FUN1(27,17,XF18,ZF18,P0Q18)
C*****OR SUBSTITUTE FNZ18=SQRT(1.-P0Q18**(2./7.))
```

```
      V18=109.6*SQRT(TT18)*FNZ18*CV18
      FGROSS=WG18*V18*.0311
   54 FRAM=W1*V0*0.031085
      FN=FGROSS-FRAM
C*****CORE INLET AIR TEMPERATURE SENSOR
      TAUT25=FUN1(28,10,XF81,ZF81,1.38*W25)
      TT25DT=(TT25-T25SN)/TAUT25
      TH25SN=T25SN/605.4
      RTH25S=SQRT(TH25SN)
C*****FUEL CONTROL
      NHD=154.5*PCNHRD*RTH25S
      NHD=AMIN1(NHD,17000.)
      NHD=AMAX1(NHD,8795.)
      NHERR=NH-NHD
      CONST=SQRT(WFH)*NH*1.494E-6
      WFPROP=-2.29*NHERR*CONST
      CON=-3.21
      IF(WFC2.NE.WFGV) CON=0.
      WFIDT=NHERR*CON*CONST
      WFGOV=WFPROP+WFI
      WFSCH=FUN2(29,24,5,XNH,YTT25,ZWFSCH,NH,T25SN)
      WFACMX=-.0134*NH+234.1
      IF(WFSCH.GT.WFACMX) WFSCH=WFACMX
      IF(PS3.LE.200.) PC=PS3
      IF(PS3.GT.200.) PC=200.+(PS3-200.)*(-2.)
      WFACC=WFSCH*PC
      WFDEC=.385*WFACC
      WFC1=AMIN1(WFACC,WFGOV)
      WFC1=AMAX1(WFC1,WFDEC)
      WFC1=AMIN1(WFC1,4438.)
      WFC1=AMAX1(WFC1,295.858)
      WFC2=WFC1
      WFGV=WFGOV
      WFHDT=(WFC1-WFH)/.05
C*****FAN PITCH ACTUATOR
      BETADT=10.*(BETAFD-BETAF)
      IF(ABS(BETADT).GT.100.) BETADT=SIGN(100.,BETADT)
      RETURN
      END
```

Subroutine ENGN3D

This subroutine is called from DVTOL and computes variables for the turbine engine and remote fan propulsion unit number 3. The equations of ENGN1D have been modified to allow separation of the fan and turbojet units. ENGN3D does not contain the core failure option but could be easily modified to do so.

ENG3 ,10/24/80 09:14:00

```
      SUBROUTINE ENGN3D
      REAL MN0,NL,NLDT,NH,NHDT,NHD,NHERR
      COMMON /XX1/ ALT,MN0,AE8,CV8,CV18,PS3GS,PT8GS,QX
      COMMON /XX2/ XALT(8),ZPFA(8),ZTFA(8),XPCNH2(16),ZETAC(16),-
     A XPCNH1(12),ZW25R(12),XF18(17),ZF18(17),XF81(10),ZF81(10),YY(50),DYDT(50)
      COMMON /FAN/ XBETA(7),YPCNLR(5),ZFFLOW(7,5),ZFTPR(7,5),ZFTTR(7,5)
      COMMON/CORE/XNH(24),YTT25(5),ZWFSCH(24,5)
      COMMON/FANSTL/XBETA2(5),ZWSTL(5,5),ZPRSTL(5,5)
      COMMON /YY3/ NL,NH,T3L,T4L,PT0SN,T12SN,T3SN.ERLINT,X18,T25SN,QMVLG,XMV,-
     A BETAF,XXA,XXB,WFI
      COMMON /DYDT3/ NLDT,NHDT,T3LDT,T4LDT,PT0SDT,T12SDT,T3SDT,ERNLDT,X18DT,-
     A TT25DT,QMVLDT,XMVDT,BETADT,XXADT,XXBDT,WFIDT,WFHDT
      COMMON /SIDE3/-
     A A18    ,WFH    ,PCNLRD,XXKI  ,XXKP  ,P0    ,T0    ,P11   ,T11   ,TT2   ,-
     B V0     ,PCNLR  ,P13Q2 ,T13Q2 ,W1    ,PT2   ,PT13  ,TT13  ,PT25  ,TT25  ,-
     C PCNHR  ,W25R   ,W25   ,P13Q18,PT18  ,P0Q18 ,WA18  ,W3    ,WG4   ,WFM   ,-
     D PS3    ,PT3    ,P3QP25,TT3   ,TT4   ,PT4   ,TT42  ,WG8   ,PT8   ,PT42  ,-
     E TT8    ,HP1T   ,HPF   ,HP2T  ,WFHI  ,HP2C  ,P0Q8  ,V8    ,V18   ,FGROSS,-
     F FRAM   ,FN     ,WFMPSS,WFMPTP,WFMPST,WFMQK ,PHI   ,PS3C  ,WFACC,FNZ18 ,-
     G WG18   ,WFDEC,XMVDEC,TT18  ,ERRNL ,PCNHRD,QNH   ,QMV   ,HPX   ,BETAFD,-
     H SM
      ITR3S=0
      RTH2=SQRT(TT2/518.67)
      QRTH2=1./RTH2
      RTT0=SQRT(T0)
      V0=49.018*MN0*RTT0
C*****ENGINE MODEL
  600 CONTINUE
C*****FAN CALCULATIONS
      PCNLR=NL/36./(SQRT(TT2/556.))
      IF(PCNLR .GT. 0.) GO TO 1
      W1R=0.
      P13Q2=1.
      T13Q2=1.
      GO TO 2
    1 W1R=FUN2(30,7,5,XBETA,YPCNLR,ZFFLOW,BETAF,PCNLR)
      P13Q2=FUN2(31,7,5,XBETA,YPCNLR,ZFTPR,BETAF,PCNLR)
      T13Q2=FUN2(32,7,5,XBETA,YPCNLR,ZFTTR,BETAF,PCNLR)
      IF(W1R .LT. 0.) W1R=0.
      IF(T13Q2 .LT. 1.) T13Q2=1.0
      IF(P13Q2 .LT. 1.) P13Q2=1.0
    2 W1=W1R*(PT2/14.696)*QRTH2
C*****FAN STALL MARGIN CALCULATIONS
      WSTL=FUN2(8,5,5,XBETA2,YPCNLR,ZWSTL,BETAF,PCNLR)
      PRSTL=FUN2(9,5,5,XBETA2,YPCNLR,ZPRSTL,BETAF,PCNLR)
      SM=100.*((PRSTL*W1R/P13Q2/(WSTL*.0929*17.18/.4536))-1.)
      PT13=P13Q2*PT2
      TT13=T13Q2*TT2
      RTT13=SQRT(TT13)
C*****FAN DUCT CALCULATIONS
      PT18=.99*PT13
      WA18=W1
      PT25=PT2
```

```
      TT25=TT2
      QRTH25=1.0/SQRT(TT25*1.928E-3)
C*****COMPRESSOR CALCULATIONS
      PCNHR=NH/154.5/(SQRT(TT25/605.4))
      W25R=1.013*FUN1(33,12,XPCNH1,ZW25R,PCNHR)
      ETAC=FUN1(34,16,XPCNH2,ZETAC,PCNHR)
      W25=W25R*.068046*PT25*QRTH25
   34 W3=.9036*W25
      WFM=WFH/3600.
      WG4=WFM+W3+.025*W25
      FREQ2=0.0104*W3
      TAU1=0.843/FREQ2
      FREQ4=0.0240*WG4
      TAU3=0.868/FREQ4
C*****ITERATE FOR COMPRESSOR DISCHARGE STATIC PRESSURE
C*******HEAT SOAK DYNAMICS
      KPS3=0
   35 ITR3S=ITR3S+1
      PS3=PS3GS
      IF(PS3.LT.1.0) PS3=1.0
      PT3=1.057*PS3
      P3QP25=PT3/PT25
      T3Q25=1.+(P3QP25**.2857-1.)/ETAC
      TT3P=T3Q25*TT25
      T3LDT=(TT3P-T3L)*FREQ2
      TT3=TAU1*T3LDT+T3L
      TT4P=53233.*(WFM/W3)+159.+TT3
      T4LDT=(TT4P-T4L)*FREQ4
      TT4=TAU3*T4LDT+T4L
      PS3=.0812*WG4*SQRT(TT4)
      ERR=PS3-PS3GS
      CALL CNVRG1(8,ERR,PS3,PS3GS,.0002,ITR3S,KPS3)
      IF(KPS3.EQ.1)GO TO 40
      GO TO 35
   40 CONTINUE
      PT4=PS3
C*****HIGH AND LOW TURBINE EXIT CONDITIONS
      TT42=.7897*TT4
      WG8=W25+WFM
      PT42=.300*PT4
      PT8=.01533*WG8+P0
      TT8Q42=1.-(1.-(PT8/PT42)**.248)*.866
      TT8=TT42*TT8Q42
C*****FAN ROTOR DYNAMICS
      HP1T=.3817*WG8*(TT42-TT8)
      HPF=.3623*WA18*(TT13-TT2)
C*****CORE ROTOR DYNAMICS
      HP2T=.417*WG4*(TT4-TT42)
      HP2C=.369*W3*(TT3-TT25)
      NHDT=37710./NH*(HP2T-HP2C)
C*****THRUST CALCULATIONS
      P0Q18=P0/PT18
      FNZ18=FUN1(35,17,XF18,ZF18,P0Q18)
```

```
C*****OR SUBSTITUTE FNZ18=SQRT(1.-P0Q18**(2./7.))
      IF(FNZ18 .LT. 0.) FNZ18=0.
      V18=109.61*RTT13*FNZ18*CV18
      FGROSS=.0311*WA18*V18
   54 FRAM=W1*V0*0.031085
      FN=FGROSS-FRAM
C*****CORE INLET AIR TEMPERATURE SENSOR
      TAUT25=FUN1(36,10,XF81,ZF81,1.38*W25)
      TT25DT=(TT25-T25SN)/TAUT25
      TH25SN=T25SN/605.4
      RTH25S=SQRT(TH25SN)
C*****FUEL CONTROL
      NHD=154.5*PCNHRD*RTH25S
      NHD=AMIN1(NHD,17000.)
      NHD=AMAX1(NHD,8795.)
      NHERR=NH-NHD
      CONST=SQRT(WFH)*NH*1.494E-6
      WFPROP=-2.29*NHERR*CONST
      CON=-3.21
      IF(WFC2.NE.WFGV) CON=0.
      WFIDT=NHERR*CON*CONST
      WFGOV=WFPROP+WFI
      WFSCH=FUN2(37,24,5,XNH,YTT25,ZWFSCH,NH,T25SN)
      WFACMX=-.0134*NH+234.1
      IF(WFSCH.GT.WFACMX) WFSCH=WFACMX
      IF(PS3.LE.200.) PC=PS3
      IF(PS3.GT.200.) PC=200.+(PS3-200.)*(-2.)
      WFACC=WFSCH*PC
      WFDEC=.385*WFACC
      WFC1=AMIN1(WFACC,WFGOV)
      WFC1=AMAX1(WFC1,WFDEC)
      WFC1=AMIN1(WFC1,4438.)
      WFC1=AMAX1(WFC1,295.858)
      WFC2=WFC1
      WFGV=WFGOV
      WFHDT=(WFC1-WFH)/.05
C*****FAN PITCH ACTUATOR
      BETADT=10.*(BETAFD-BETAF)
      IF(ABS(BETADT).GT.100.) BETADT=SIGN(100.,BETADT)
      RETURN
      END
```

Subroutine CNVRG1(N,ERR,XOLD,XNEW,TOL,ITR,IND)

A convergence subroutine called from the iteration loops of the ENGNyD subroutines to find compressor-exit static pressure (PS3). The agruments are as follows:

N = parameter used to keep track of what variable is being iterated on when CNVRG1 is used for more than one iteration loop.

ERR = difference between latest calculated value and latest guessed value.

XOLD = latest calculated value (in ENGNyD)

XNEW = latest guessed value (from CNVRG1)

TOL = sets tolerance on largest difference between latest guessed value and latest calculated value within which convergence is assumed to occur.

IND = Index set in CNVRG1 indicating whether or not convergence is complete.

ITR = number of iteration loops (maximum of 50,000 per pass through ENGNyD).

```
XHCNVRG1,09/19/80 12:38:17

      SUBROUTINE CNVRG1(N,ERR,XOLD,XNEW,TOL,ITR,IND)
      DIMENSION XV1(10),XV2(10),XR1(10),XR2(10)
      IF(ITR.GT.50000) CALL EXIT
      RELTOL=TOL*ABS(XOLD)
      IF(ABS(ERR).LT.RELTOL) GO TO 30
      XV2(N)=XV1(N)
      XR2(N)=XR1(N)
      XV1(N)=XOLD
      XR1(N)=ERR
      IF(ITR.GE.2) GO TO 20
      XNEW=XNEW*1.04
      RETURN
   20 IF(XR1(N).NE.XR2(N)) GO TO 25
      XNEW=XNEW*1.01
      RETURN
   25 XNEW=XV1(N)-XR1(N)*(XV2(N)-XV1(N))/(XR2(N)-XR1(N))
      RETURN
   30 IND=1
      XNEW=XOLD
      RETURN
      END
```

Block Data

BLOCK DATA contains some miscellaneous constants and coefficients as well as all of the tables of data that are functions of one or two variables. These data include items such as: ambient temperature and pressure as functions of altitude; fan airflow and temperature and pressure ratios as functions of fan speed and fan-blade pitch angle; and core-compressor airflow and efficiency as functions of core speed.

```
      BLOCK DATA
      REAL MNO
      COMMON /XX1/ ALT,MNO,AE8,CV8,CV18,PS3GS,PT8GS,QX,ICF
      COMMON /XX2/ XALT(8),ZPFA(8),ZTFA(8),XPCNH2(16),ZETAC(16),-
     AXPCNH1(12),ZW25R(12),XF18(17),ZF18(17),XF81(10),ZF81(10),YY(50),DYDT(50)
      COMMON /FAN/ XBETA(7),YPCNLR(5),ZFFLOW(7,5),ZFTPR(7,5),ZFTTR(7,5)
      COMMON /HUB/ XBETA1(8),ZFHPR(8,5),ZFHTR(8,5)
      COMMON /CORE/ XNH(24),YTT25(5),ZWFSCH(24,5)
      COMMON/FANSTL/XBETA2(5),ZWSTL(5,5),ZPRSTL(5,5)
      DATA ALT,MNO,AE8,CV8,CV18/0.0,0.0,371.7,.997,.985/
      DATA PS3GS,PT8GS/196.8,16.31/
      DATA XF18/.5,.55,.6,.65,.7,.75,.8,.85,.9,.92,.94,.95,.96,.97,.98,.99,1./
      DATA ZF18/.4239,.3963,.3685,.3403,.3113,.2809,.2485,.2130,.1722,-
     A.1534,.1324,.1206,.1077,.0931,.0759,.0536,0.0/
      DATA XF81/9.5,11.4,15.2,19.0,22.8,28.5,38.0,47.5,57.0,76.0/
      DATA ZF81/3.06,2.72,2.22,1.89,1.64,1.38,1.13,0.97,0.85,0.72/
      DATA XPCNH1/65.,70.,75.,80.,82.5,85.,90.,92.5,96.,100.,105.,107.5/
      DATA ZW25R/12.2,14.0,16.2,18.9,20.8,24.2,29.7,32.9,37.2,41.2,-
     A 44.1,44.9/
      DATA XPCNH2/65.,70.,78.5,82.1,85.,86.69,87.28,90.07,91.13,92.78,-
     A 94.39,95.28,97.65,98.35,102.23,106.39/
      DATA ZETAC/.78,.79,.8,.81,.82,.83,.832,.839,.842,.844,.845,.846,-
     A .844,.843,.833,.804/
      DATA XALT/0.0,5.E3,1.E4,1.5E4,2.E4,2.5E4,3.E4,3.5E4/
      DATA ZPFA/14.696,12.228,10.107,8.294,6.754,5.453,4.365,3.458/
      DATA ZTFA/518.67,500.85,483.03,465.21,447.39,429.57,411.75,393.93/
      DATA XBETA/-20.,-15.,-10.,-5.,0.,5.,7.3/
      DATA YPCNLR/70.,80.,90.,100.,110./
      DATA ZFFLOW/-
     A 295.,342.,389.,435.,476.,504.,513.,-
     B 336.,389.,442.,495.,543.,577.,589.,-
     C 378.,437.,497.,556.,607.,650.,666.,-
     D 421.,485.,549.,612.,669.,719.,739.,-
     E 463.,530.,597.,664.,716.,750.,761./
      DATA ZFTPR/-
     A 1.039, 1.049, 1.063, 1.080, 1.097, 1.110, 1.114, -
     B 1.049, 1.064, 1.083, 1.105, 1.127, 1.145, 1.152, -
     C 1.060, 1.081, 1.105, 1.133, 1.160, 1.187, 1.200, -
     D 1.077, 1.101, 1.130, 1.164, 1.199, 1.232, 1.246, -
     E 1.092, 1.122, 1.156, 1.196, 1.231, 1.255, 1.262/
      DATA ZFTTR/-
     A 1.0135, 1.0172, 1.0211, 1.0253, 1.0300, 1.0352, 1.0381, -
     B 1.0175, 1.0223, 1.0273, 1.0328, 1.0390, 1.0463, 1.0503, -
     C 1.0215, 1.0281, 1.0347, 1.0416, 1.0490, 1.0581, 1.0633, -
     D 1.0266, 1.0345, 1.0427, 1.0513, 1.0605, 1.0714, 1.0775, -
     E 1.0323, 1.0418, 1.0520, 1.0632, 1.0733, 1.0832, 1.0879/
      DATA XBETA1/-20.,-13.,-9.,-7.,-4.,1.,4.,7.3/
      DATA ZFHPR/-
     A 1.059, 1.065, 1.070, 1.074, 1.078, 1.081, 1.081, 1.077, -
     B 1.086, 1.089, 1.092, 1.094, 1.100, 1.105, 1.105, 1.105, -
     C 1.109, 1.115, 1.119, 1.122, 1.128, 1.136, 1.141, 1.146, -
     D 1.140, 1.141, 1.144, 1.151, 1.162, 1.175, 1.187, 1.185, -
     E 1.167, 1.175, 1.177, 1.180, 1.200, 1.213, 1.224, 1.249/
```

```
      DATA ZFHTR/-
     A 1.0214, 1.0241, 1.0264, 1.0282, 1.0309, 1.0342, 1.0360, 1.0376, -
     B 1.0294, 1.0325, 1.0352, 1.0369, 1.0395, 1.0445, 1.0479, 1.0516, -
     C 1.0374, 1.0409, 1.0443, 1.0463, 1.0498, 1.0561, 1.0605, 1.0653, -
     D 1.0469, 1.0504, 1.0536, 1.0563, 1.0621, 1.0702, 1.0761, 1.0811, -
     E 1.0570, 1.0610, 1.0642, 1.0680, 1.0755, 1.0844, 1.0906, 1.0994/
      DATA XNH/9000.,9500.,10000.,10500.,10750.,11000.,11500.,12000.,-
     A 12500.,13000.,13500.,13750.,14000.,14200.,15800.,16000.,16100.,-
     B 16200.,16250.,16300.,16400.,16500.,17000.,17500./
      DATA YTT25/394.67,459.67,518.67,584.67,624.67/
      DATA ZWFSCH/18.8,18.2,17.1,16.4,16.25,16.35,17.7,19.5,21.7,24.5,-
     A 26.7,27.5,27.9,28.,28.,27.6,26.,24.4,23.6,22.94,21.62,20.3,-
     B 13.15,6.,18.5,17.7,16.7,16.,15.9,16.,17.,18.7,20.8,22.7,24.6,-
     C 25.4,25.7,25.9,25.9,25.8,25.6,24.275,23.61,22.95,21.62,20.3,-
     D 13.15,6.,18.2,17.2,16.25,15.65,15.6,15.65,16.5,17.9,19.9,21.8,-
     E 23.3,24.1,24.75,25.,25.,25.,24.8,24.6,23.88,23.17,21.73,20.3,-
     F 13.15,6.,17.8,16.8,15.85,15.4,15.3,15.4,16.,17.4,19.1,21.,22.5,-
     G 23.25,23.6,23.7,23.7,23.7,23.7,23.55,23.475,23.4,21.85,20.3,-
     H 13.,6.,17.4,16.4,15.6,15.1,15.,15.1,15.75,16.9,18.4,20.,21.7,-
     I 22.4,22.9,23.,23.,23.,23.,23.,22.9,22.8,22.,20.3,13.15,6./
      DATA XBETA2/-17.2,-4.1,0.,4.,7.3/
      DATA ZWSTL/ -
     A 72.3,96.8,101.6,116.,132.8, -
     B 83.7,111.2,117.2,137.2,154.4, -
     C 96.7,127.6,138.,156.,173.2, -
     D 110.,145.6,156.8,172.4,192.4, -
     E 123.3,165.6,174.8,190.4,211.5/
      DATA ZPRSTL/ -
     A 1.0883,1.1120, 1.1124,1.1128,1.1128, -
     B 1.1153,1.1448,1.1432,1.1464,1.1456, -
     C 1.1483,1.1888,1.1852,1.1828,1.1880, -
     D 1.1840,1.2240,1.2408,1.2352,1.2536, -
     E 1.2233,1.3040,1.3024,1.3072,1.3200/
      END
```

FUNCTION FUN1 (N,NXP,XX,ZZ,XIN)

Function routine used in DVTOL and ENGNyD routines to linearly interpolate tables of data having one dependent and one independent variable. Results are obtained by extrapolation if the range of the table is exceeded. The arguments are as follows:

N = a parameter used to keep track of which data table is being interpolated.

NXP = number of XX,ZZ pairs in the table.

XX = the table of independent variables.

ZZ = the table of dependent variables.

XIN - the value of the independent variable for which the dependent variable is desired.

XHFUN1 ,09/19/80 12:39:53

```
      FUNCTION FUN1(N,NXP,XX,ZZ,XIN)
      COMMON /FMEMR/IX(60),JY(60),IERR(60)
      DIMENSION XX(NXP),ZZ(NXP)
C*****TEST FOR X IN PREVIOUS INTERVAL
      I=IX(N)
      IF(XIN-XX(I))120,200,110
  110 IF(XIN-XX(I+1))200,140,140
C*****COUNT DOWN*****
  120 IF(XIN-XX(1))160,160,130
  130 I=I-1
      IF(XIN-XX(I))130,200,200
C*****COUNT UP*****
  140 IF(XIN-XX(NXP))150,170,170
  150 I=I+1
      IF(XIN-XX(I+1))200,200,150
  160 I=1
      GO TO 180
  170 I=NXP-1
  180 IF(IERR(N))200,190,190
  190 WRITE(6,400)N,XIN
      IERR(N)=-1
C*****INTERPOLATE FOR ANSWER*****
  100 CONTINUE
  200 XFRAC=(XIN-XX(I))/(XX(I+1)-XX(I))
      FUN1=ZZ(I)+XFRAC*(ZZ(I+1)-ZZ(I))
      IX(N)=I
      RETURN
  400 FORMAT(1H0,12HFUNCTION NO.,I3,20H  INPUT OUT OF RANGE,
     12X,6HXIN = ,G12.4)
      END
```

FUNCTION FUN2(N,NXP,NYC,XX,YY,ZZ,XIN,YIN)

A function routine used in DVTOL and ENGNyD subroutines to linearly interpolate tables of data having one dependent and two independent variables. Results are obtained by extrapolation if the range of the table is exceeded. The arguments are as follows:

N = a parameter used to keep track of which data table is being interpolated.

NXP = number of XX,ZZ pairs in the table of a constant value of YY.

NYC = number of YY's.

XX = the table containing one set of independent variable.

YY = the table containing the other set of independent variable.

ZZ = the table of dependent variables.

XIN,YIN = values of the two independent variables for which the dependent variable is desired

XHFUN2 ,09/19/80 12:40:23

```
      FUNCTION FUN2(N,NXP,NYC,XX,YY,ZZ,XIN,YIN)
      COMMON /FMEMR/IX(60),JY(60),IERR(60)
      DIMENSION XX(NXP),YY(NYC),ZZ(NXP,NYC)
      I = IX(N)
      J = JY(N)
C*****TEST FOR X IN PREVIOUS INTERVAL*****
      IF(XIN-XX(I)) 120,200,110
  110 IF(XIN-XX(I+1)) 200,140,140
C*****COUNT DOWN*****
  120 IF(XIN-XX(1)) 160,160,130
  130 I = I-1
      IF(XIN-XX(I)) 130,200,200
C*****COUNT UP*****
  140 IF(XIN-XX(NXP)) 150,170,170
  150 I = I+1
      IF(XIN-XX(I+1)) 200,200,150
  160 I = 1
      GO TO 180
  170 I = NXP-1
  180 IF(IERR(N)) 200,190,190
  190 WRITE(6,400) N,XIN,YIN
      IERR(N) = -1
C*****TEST FOR Y IN PREVIOUS INTERVAL*****
  200 IF(YIN-YY(J)) 220,300,210
  210 IF(YIN-YY(J+1)) 300,240,240
C*****COUNT DOWN*****
  220 IF(YIN-YY(1)) 260,260,230
  230 J = J-1
      IF(YIN-YY(J)) 230,300,300
C*****COUNT UP*****
  240 IF(YIN-YY(NYC)) 250,270,270
  250 J = J+1
      IF(YIN-YY(J+1)) 300,300,250
  260 J = 1
      GO TO 280
  270 J = NYC-1
  280 IF(IERR(N)) 300,290,290
  290 WRITE(6,400) N,XIN,YIN
      IERR(N) = -1
C*****INTERPOLATE FOR ANSWER*****
  300 XFRAC = (XIN-XX(I))/(XX(I+1)-XX(I))
      P1ZZ = ZZ(I,J)+XFRAC*(ZZ(I+1,J)-ZZ(I,J))
      P2ZZ = ZZ(I,J+1)+XFRAC*(ZZ(I+1,J+1)-ZZ(I,J+1))
      YFRAC = (YIN-YY(J))/(YY(J+1)-YY(J))
      FUN2 = P1ZZ+YFRAC*(P2ZZ-P1ZZ)
      IX(N) = I
      JY(N) = J
      RETURN
  400 FORMAT(1H0,12HFUNCTION NO.,I3,20H INPUTS OUT OF RANGE,
     12X,6HXIN = ,G12.4,2X,6HYIN = ,G12.4)
      END
```

SUBROUTINE EULERM(DYDT,YY)

This subroutine is called from DVTOL and is used to find the integrals YY of the derivative terms DYDT. A modified Euler method is used as outlined in reference 7.

XXEULRM ,09/19/80 12:36:55

```
      SUBROUTINE EULERM(DYDT,YY)
C*****MODIFIED EULER METHOD - REF. MCCRACKEN & DORN P322
      COMMON /INTVAL/DT1,DT2,ICOUNT
      DIMENSION DYDT(50),YY(50),YYSV(50)
      ICOUNT=ICOUNT+1
      IF(ICOUNT) 5,5,20
    5 DO 10 I=1,50
      YYSV(I)=YY(I)
      YY(I)=YY(I)+DT2*DYDT(I)
   10 CONTINUE
      GO TO 40
   20 DO 30 I=1,50
      YY(I)=YYSV(I)+DT1*DYDT(I)
   30 CONTINUE
   40 RETURN
      END
```

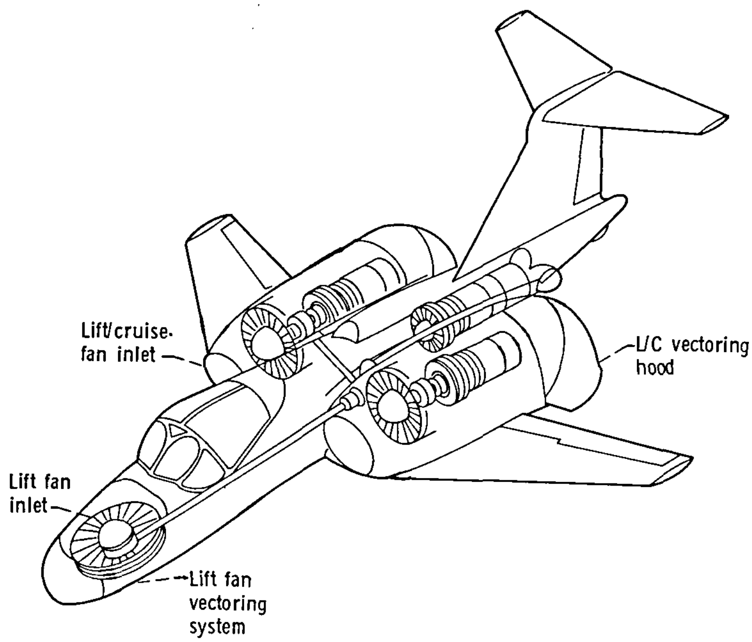


Figure 1. - Sketch of research and technology aircraft showing installation of propulsion system.

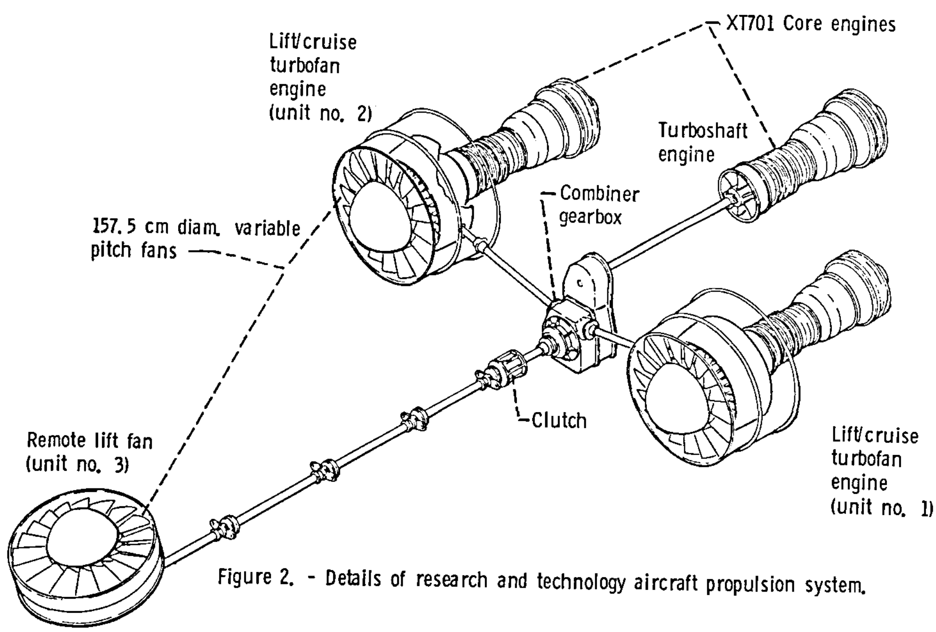
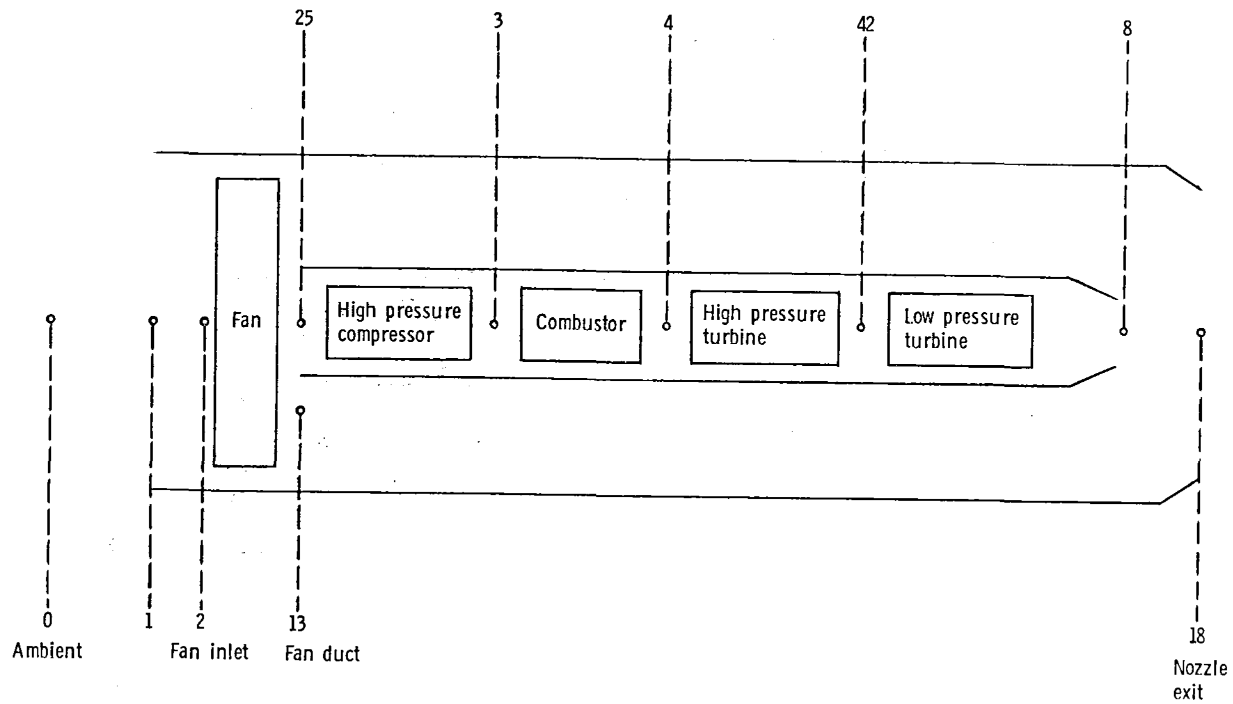
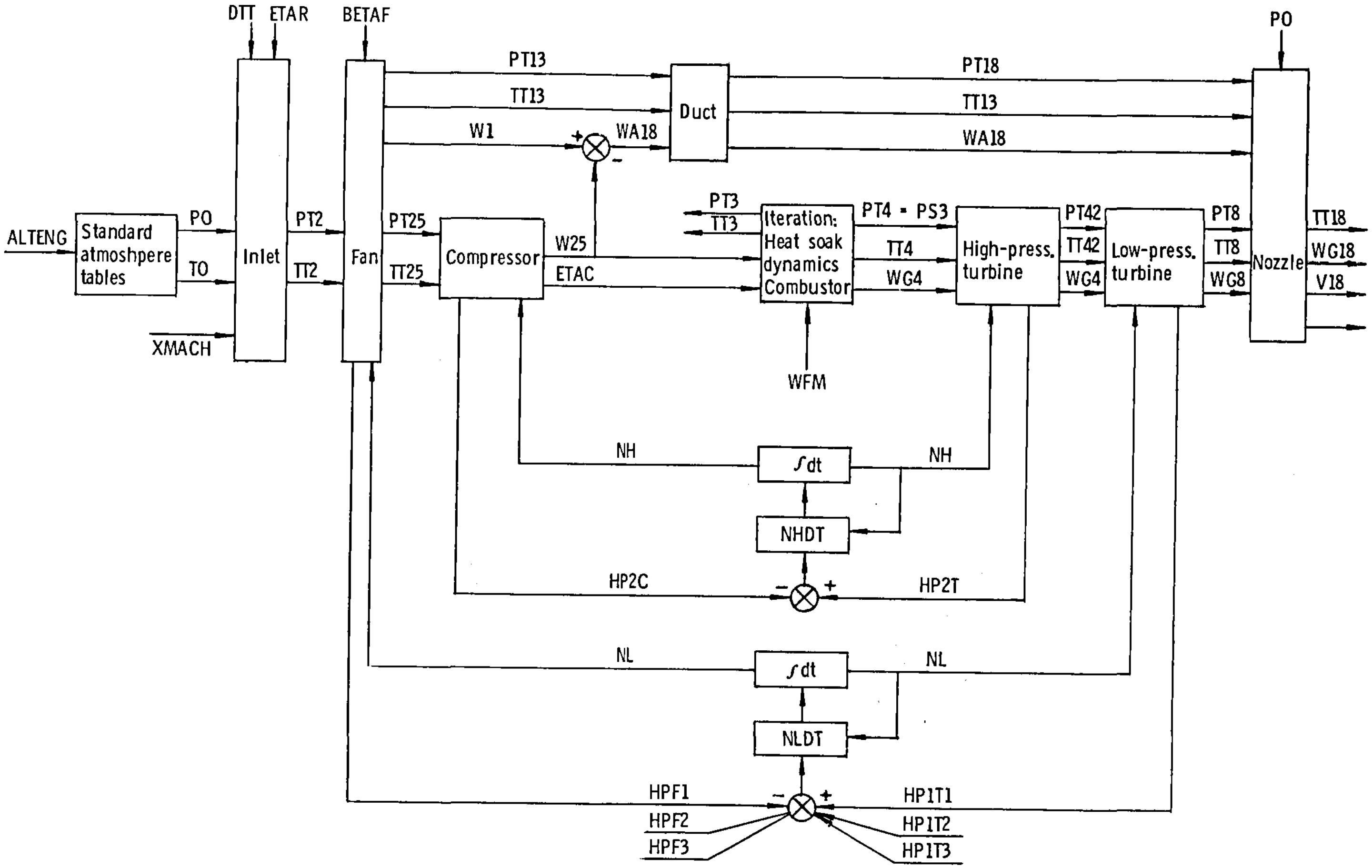


Figure 2. - Details of research and technology aircraft propulsion system.



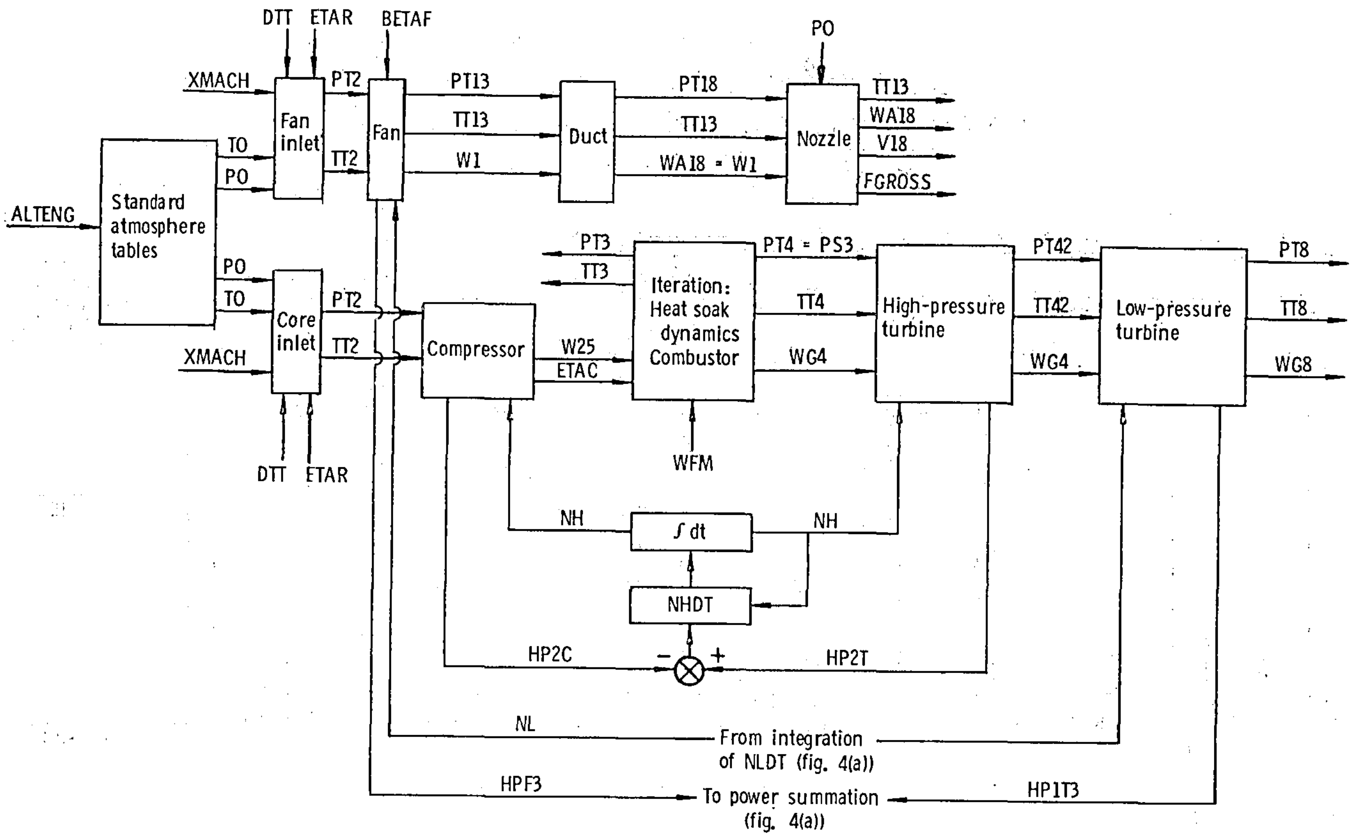
For propulsion unit no. 3:
Conditions at stations 2 and 25 are equal (turboshaft engine inlet)
temperature at stations 13 and 18 are equal (remote fan exit)

Figure 3. - Propulsion station numbers for LeRC model.



(a) Lift/cruise turbofan (units 1 and 2).

Figure 4. - Computational flow diagram of propulsion system model.



(b) Turboshaft/remote fan (unit 3).

Figure 4. - Concluded.

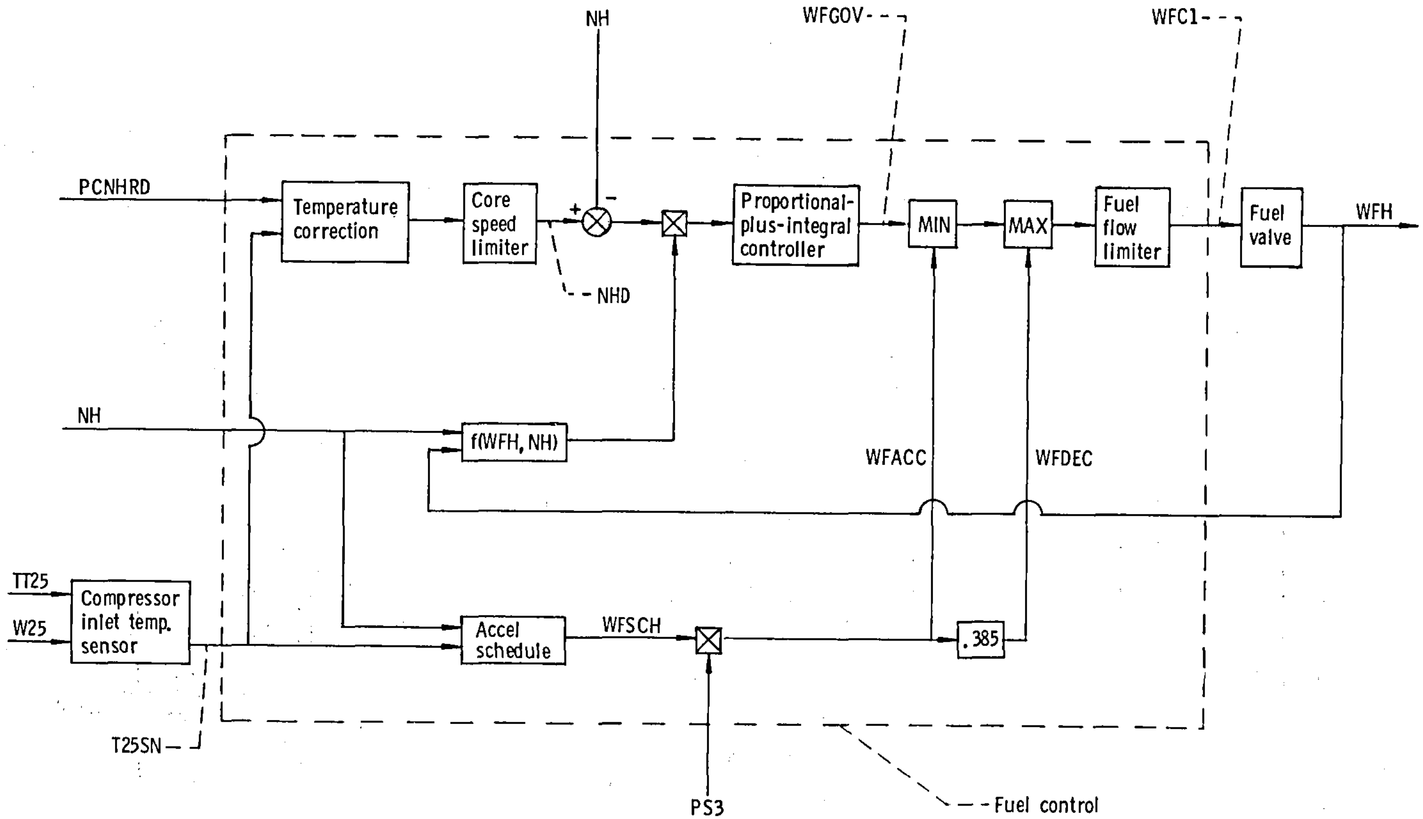
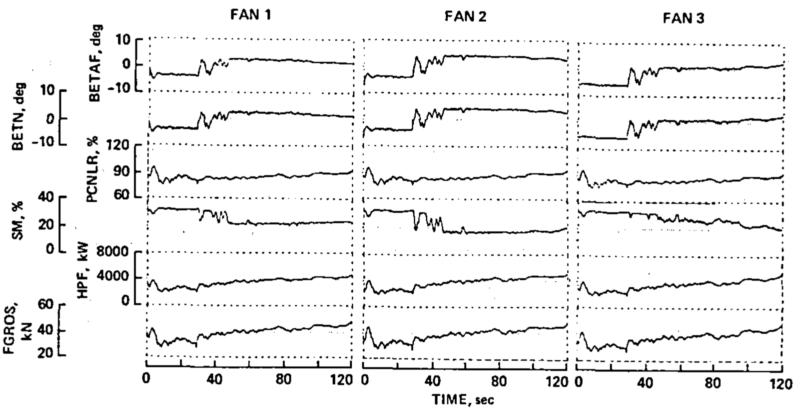
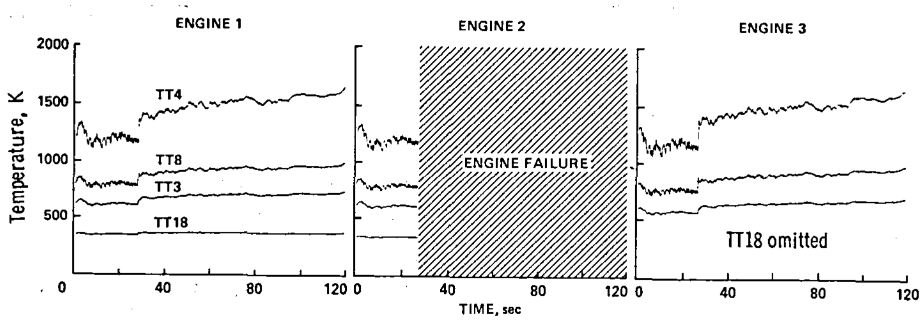


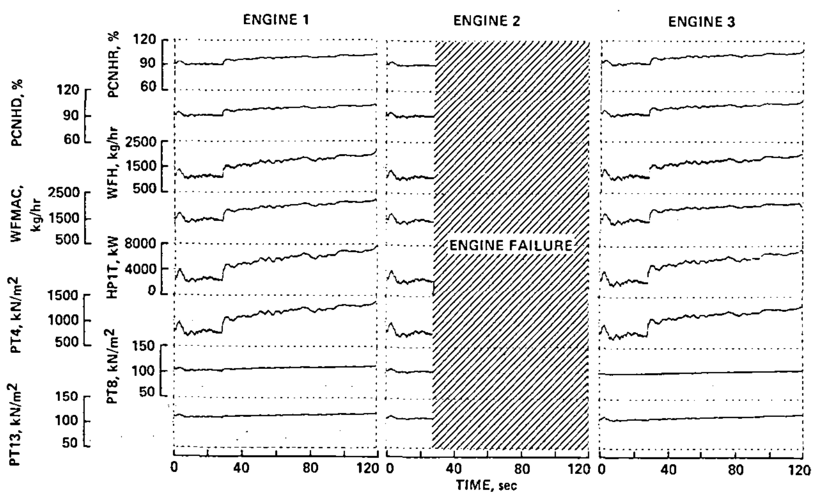
Figure 5. - Fuel control details.



(a) Fan variables.



(b) Engine temperatures.



(c) Engine variables.

Figure 6. - Propulsion system data for typical approach. Conditions: aircraft gross weight, maximum; wind, 20 kts. at 30° from flight path heading; turbulence rms level, 1 m/sec; hot day temperature, 32.2° C. No fan blade actuator deadband. Engine number 2 failure at 28 sec.

1. Report No. NASA TM-81663	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PROPULSION SYSTEM MATHEMATICAL MODEL FOR A LIFT/CRUISE FAN V/STOL AIRCRAFT		5. Report Date December 1980
		6. Performing Organization Code 532-05-12
7. Author(s) Gary L. Cole and James F. Sellers, Lewis Research Center and Bruce E. Tinling, Ames Research Center, Moffett Field, California		8. Performing Organization Report No. E-681
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A propulsion system mathematical model is documented that allows calculation of internal engine parameters during transient operation. A non-real-time digital computer simulation of the model is also presented. It can be used to investigate thrust response and modulation requirements as well as the impact of duty cycle on engine life and design criteria. Comparison of simulation results with steady-state cycle deck calculations showed good agreement. The model was developed for a specific 3-fan subsonic V/STOL aircraft application but it could be adapted for use with any similar lift/cruise V/STOL configuration.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
V/STOL; Type A; Turbofan; Turboshaft engine; Variable pitch; Lift/cruise; Fan; Computer simulation	Unclassified - unlimited STAR Category 07

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

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